

A search for ram-pressure stripping in the Hydra I cluster

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Abstract

Ram-pressure stripping is a method by which hot interstellar gas can be removed from a galaxy moving through a group or cluster of galaxies. Indirect evidence of ram-pressure stripping includes lowered X-ray brightness in a galaxy due to less X-ray emitting gas remaining in the galaxy. Here we present the initial results of our program to determine whether cluster elliptical galaxies have lower hot gas masses than their counterparts in less rich environments. This test requires the use of the high-resolution imaging of the *Chandra* Observatory and we present our analysis of the galaxies in the nearby cluster Hydra I.

Introduction

A thorough understanding of the processes that drive x-ray emission in elliptical and S0 galaxies has been long sought after. Characteristics intrinsic of individual galaxies have been examined, as well as environmental influences. Of particular interest, is whether ram-pressure stripping (an environmental influence) is an observable process in early-type galaxies found in groups and clusters.

Ram-pressure stripping is one possible mechanism by which hot interstellar gas is removed from a galaxy. In this process, a galaxy moving through a galaxy cluster experiences a pressure upon its interstellar medium (ISM) by the intracluster medium (ICM). Ram-pressure can be expressed by $P_r \approx \rho_e v^2$, where ρ_e is the density of the intracluster medium, and v is the galaxy's velocity (Gunn & Gott, 1972).

This pressure could be sufficient enough to remove a significant amount of the ISM from the galaxy. Most previous studies on ram-pressure stripping effects have focused on spiral galaxies, however, even in cluster elliptical galaxies, ram-pressure stripping should be very efficient in removing the hot ISM (Toniazzi & Schindler 2001; Portnoy, Pistinner & Shaviv 1993; Lea and De Young 1976; references therein and others). As well, statistical and observational evidence exists which support the idea that ram-pressure stripping is a principal gas-removing mechanism (White & Sarazin, 1991; White et al. 1991).

An indirect search of evidence of ram-pressure stripping involves obtaining the x-ray luminosities (L_X) of galaxies in clusters. As a result of less gas in the galaxy, L_X is lowered, which may help explain the spread seen in L_X for a given $L_{optical}$ (e.g., Canizares, Fabbiano, & Trinchieri 1987; Brown & Bregman 1998).

It has previously been difficult to distinguish the X-ray emission from individual galaxies in clusters from that of the bright surrounding cluster medium. The spatial resolution of the *Chandra* X-ray Observatory now allows a better look into the ISM/ICM interaction process around bright galaxies in clusters.

Hydra I

Hydra I is a relatively nearby cluster at a redshift of $z=0.0114$ (Struble & Rood 1999), with moderate richness (richness class $R = 1$). The cluster is also known as Abell 1060, and hereafter in this paper as A1060. The cluster includes a total of ten galaxies bright enough to be listed in the NGC catalog, within $1/2$ degree of its center. There are two giant elliptical galaxies lying at the cluster center - NGC 3311 and NGC 3309.

Einstein, *ROSAT*, *ASCA*, and *Chandra* images of A1060 reveal circular X-ray contours of the ICM indicating a spherical and relaxed system (Fitchett & Merritt 1988; Tamura et al. 1996; Yamasaki et al. 2002). The ICM in A1060 is found to be fairly isothermal with $kT \sim 3.2$ keV (Furusho et al. 2001). The average cluster X-ray luminosity is found to be $L_x \sim 2 \times 10^{43}$ erg s $^{-1}$ in 2-10 keV band (Tamura et al 1996).

Observation and Data Preparation

The central region of A1060 was observed with the *Chandra* ACIS-I in June 2001 (archival observation ID 2220) for a 32 ks exposure time. The center of the cluster is located near the middle of the I3 chip.

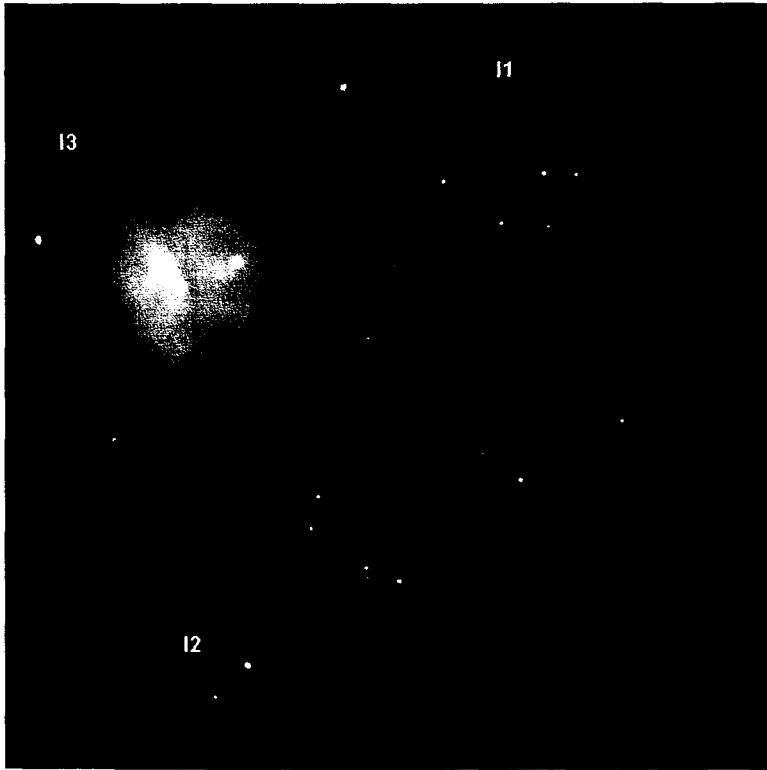


Figure 1: Adaptively smoothed *Chandra* X-ray image; 0.5 - 7 keV

Data was reprocessed following the *Chandra* X-ray Center's "ACIS Data Preparation" threads, and using CIAO analysis software version 3.0.2 and CALDB (calibration database) version 2.6. Lightcurves for each chip were examined for any periods of high background, which were subsequently removed. Losses in exposure time were minimal. Figure 1 shows an adaptively smoothed image of the ACIS-I array in the 0.5 - 7 keV range.

Analysis and Discussion

A search for early-type galaxies in A1060, using the NED database, returned approximately 30 early-type (S0 and E) galaxies whose optical positions coincide with the ACIS field of view (20 arcmin radius centered on NGC 3311). Only four galaxies had signal-to-noise ratios above 3σ (i.e. a detection): NGC 3311, NGC 3309, NGC 3308, and [R89]228. [R89]228 is object #228 in the Richter (1989) catalog of Hydra I cluster galaxies. Subsequent analysis for this paper was performed only on these four galaxies.

In Figure 2, NGC 3311 and NGC 3309 (located on chip I3) are clearly detected in both soft (0.5 - 2 keV) and hard (2 - 7 keV) X-ray bands. The ICM becomes highly dominant in the hard X-rays, due to thermal bremsstrahlung. Emission from NGC 3308 (chip I1) is detected in the soft band, but becomes faint and nearly indistinguishable from the ICM and noise in the hard band. [R89]228 (chip I2) is visible in the soft band, but disappears in the hard band.

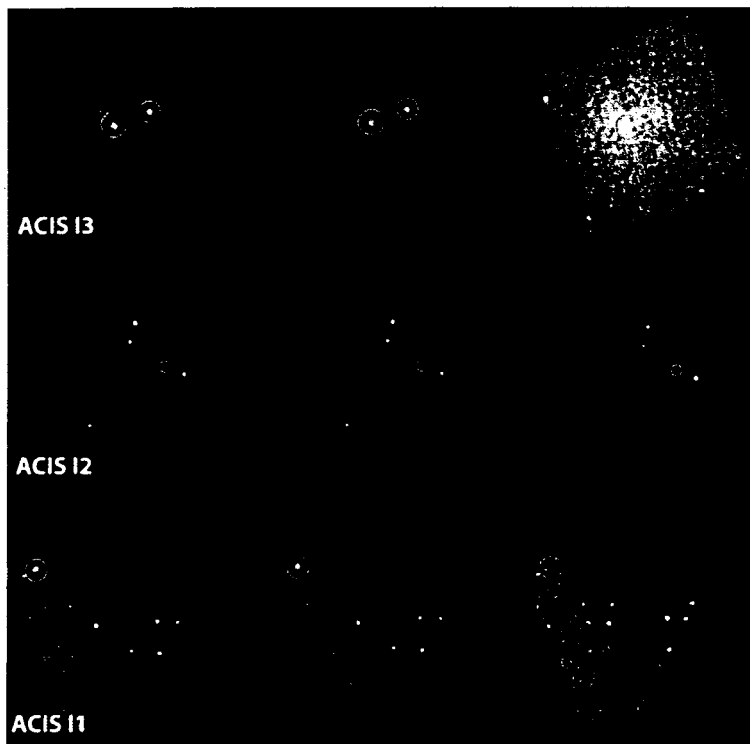


Figure 2: *Chandra* X-ray images. Galaxies examined are circled in green. Far left: 0.5-7 keV; Middle: 0.5-2 keV (soft); Far right: 2-7 keV (hard). Images logarithmically scaled.

For spectral analyses, each galaxy “source” was taken to be within 1 effective radius (calculated on the RC3 scale; a radius of 15 arcsec was used for [R89]228). For each “source,” a background was taken to be an annular region outside of the source where possible, or a nearby circular region. The background was chosen to take into account the ICM.

Single-temperature spectral fits were performed with the XSPEC 11.3.0 package. The model was a single-temperature, combined mekal + powerlaw with absorption. The mekal model is standard in fitting

the hot diffuse gas component. The powerlaw model accounts for hard emission due to discrete sources such as low-mass X-ray binaries. Abundances and temperatures were unconstrained.

Results of fits using the mekal + powerlaw model are shown in Table 1.

Table 1: Obtained fluxes for mekal + powerlaw spectral fitting

Name	total flux	flux (mekal)	flux (powerlaw)	χ^2/dof
NGC 3311	7.8177E-14	6.9230E-14	8.9469E-15	103.4/99
NGC 3309	6.2207E-14	3.3339E-14	2.8868E-14	69.5/99
NGC 3308	1.2460E-14	4.5687E-15	7.8911E-15	113.9/99
[R89]228	7.7834E-15	2.9226E-15	4.8608E-15	58.0/99

Flux in units of $\text{ergs cm}^{-2} \text{s}^{-1}$. Flux energy range is 0.5 - 2 keV. Fluxes determined within 1 effective radius.

In general, fits to the data were not acceptable. Very sub-solar abundances were determined for NGC 3311. Both NGC 3308 and [R89]228 had large error bars on the determined abundances.

X-ray gas luminosities are over-plotted on the Athey (2003) *Chandra* sample (Figure 3). An $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is assumed. Three of the four galaxies have X-ray gas luminosities consistent with a reduction of gas in the galaxies, suggesting that ram-pressure stripping may have taken place, or is taking place. Figure 1, of the ACIS-I array, shows excess emission to the northeast of NGC 3311, which is reported upon by Furusho et al. (2002), and which may be direct observational evidence of stripping from NGC 3311. [R89]228 has a much higher X-ray luminosity than expected. [R89]228 is also listed in the 2 Micron All Sky Survey Extended objects - Final Release database (as 2MASX J10361990-2739239), where it is detected in the J, H, and K_s infrared bands. A query for [R89]228 in optical and UV mission archives resulted in no matches. [R89]228 will be examined further.

Follow-up work

The analysis above has given initial results in this study. Further spectral analysis will be performed to examine whether fits will improve. Multi-temperature models will be explored, as well as constraints on abundances and alternative spectral models. Also, upper limit luminosities for galaxies detected between 1σ and 3σ will be derived. There appears excess emission to the northeast of NGC 3311, which should be examined in further detail. Finally, gas densities for the ICM and ISM for galaxies within the cluster will be derived to constrain whether other processes, besides ram-pressure stripping, are taking place.

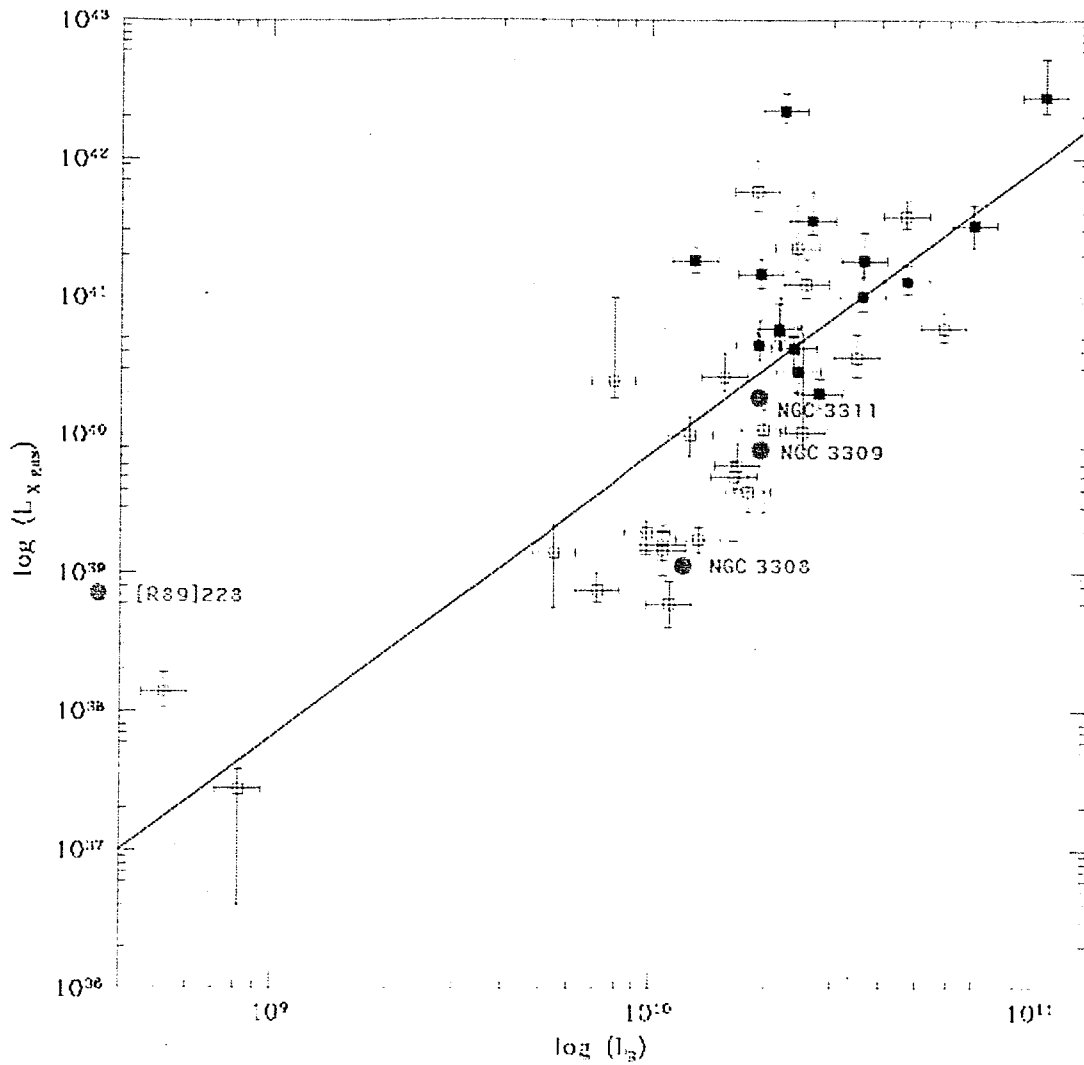


Figure 3: X-ray gas luminosities. Galaxies in red are representative of "Brightest Group Galaxies" (see Athey 2003).

References

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